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# Data Fusion of Aerodynamic Database for Flight Simulation

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**Airinnova**

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# airinnova AB - profile

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- Aerospace spin-off SME from KTH
  - ✓ Developing variable-fidelity MDO framework s & analysis tools for collaborative and *integrated* Aircraft Design
  - ✓ M. Zhang CEO
    - ✓ computational science & aeronautics : collaborative and integrated aircraft design using open-source tools
  - ✓ “middle player” role
    - ✓ equally conversant with industrial aircraft designers, software specialists, code developers and tool providers
  - ✓ offers advanced computational technology, e.g. CEASIOM framework for aircraft preliminary design
- airinnova’s strategic partnerships (universities, research institutes, companies)
  - ✓ Southampton, TU Munich, PoliMilano, Warsaw TU, MIT, Colorado U, DLR, ONERA, NLR, …
  - ✓ SAAB, Airbus Bremen, Airbus D&S Manching, Embraer, Bombardier, Alenia, CFSE (Lausanne)
  - ✓ member Aerospace Cluster Sweden, user KTH-PDC , …
  - ✓ member AIAA Aerodynamic Design Optimization Discussion Group (ADODG) - aero shape opt in constrained design
- Active in EU Projects – Aeronautics & HPC
  - ✓ Past – SimSAC, ALEF, NOVEMOR, AFLoNext
  - ✓ Current - “AGILE - Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts”
    - ✓ led by DLR
  - ✓ partner EU-project PRACE (Partnership for Advanced Computing in Europe)
    - ✓ high-level optimization in aerodynamic design - carried out in SHAPE (SME HPC Adoption Programme in Europe).
- Typical work & services provided
  - ✓ Software: CEASIOM with semi-automated mesh.gen (RANS), SUMO, Edge, SU2
  - ✓ Create variable fidelity models with surrogate model techniques & data fusion
  - ✓ Construct aircraft S&C database and loads database with variable-fidelity modeling and data fusion
  - ✓ Surrogate-based optimization; data-driven and physics-based surrogate model development
  - ✓ E.g.: Aero-elastic design of flexible struss-braced wing aircraft, simultaneous aerodynamics shape and sizing optimization

# 1. Introduction & Background

- Aircraft 3rd Generation MDO for Innovative CoLlaboration of Heterogeneous Teams of Experts
- Aircraft multidisciplinary optimization using analysis framework
- From 2015 to 2018, part of Horizon 2020
- 19 partners (Industries, Research centers, Universities)

# 1. Introduction & Background

CFS Engineering
Computational Fluids & Structures Engineering
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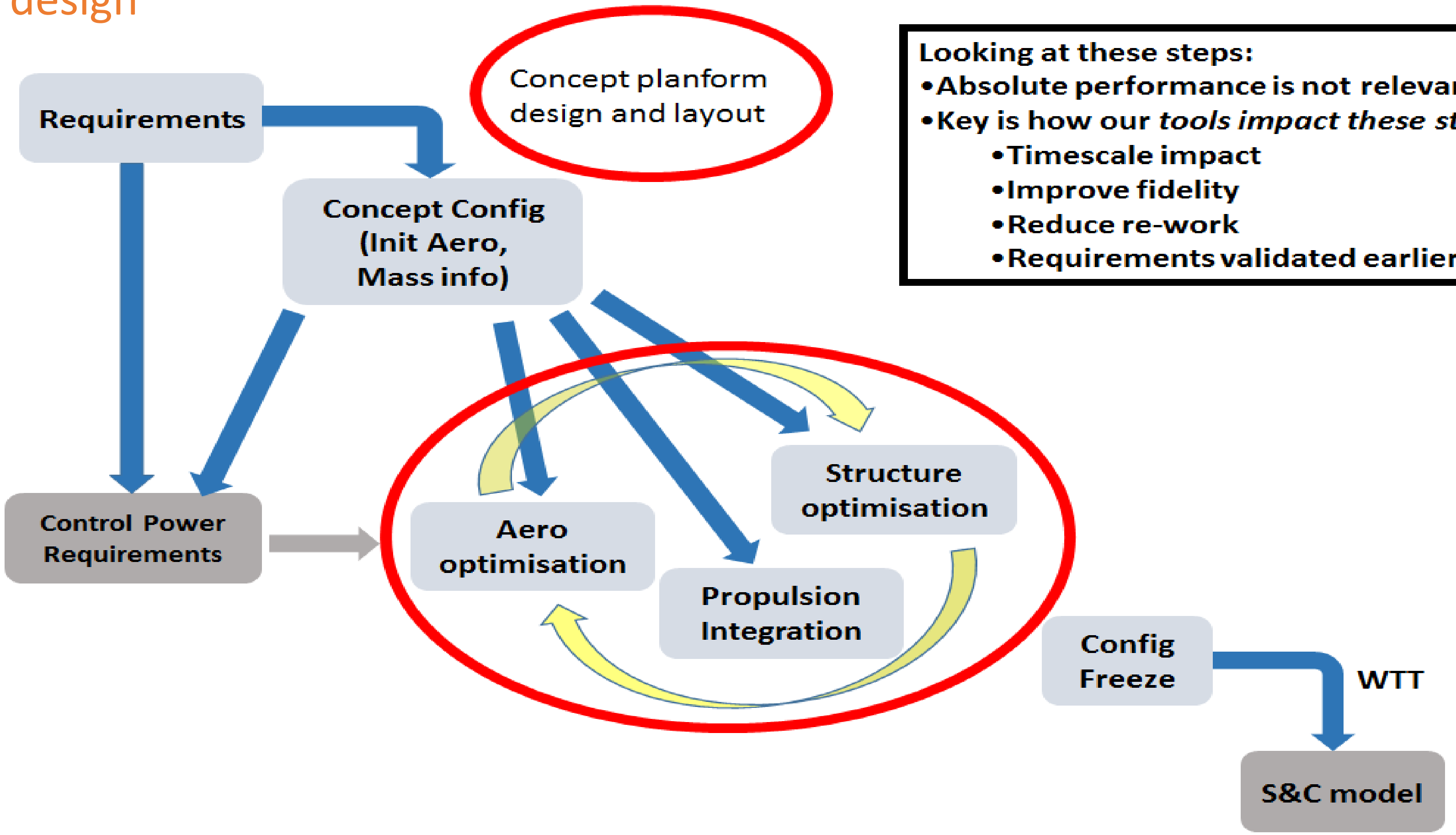
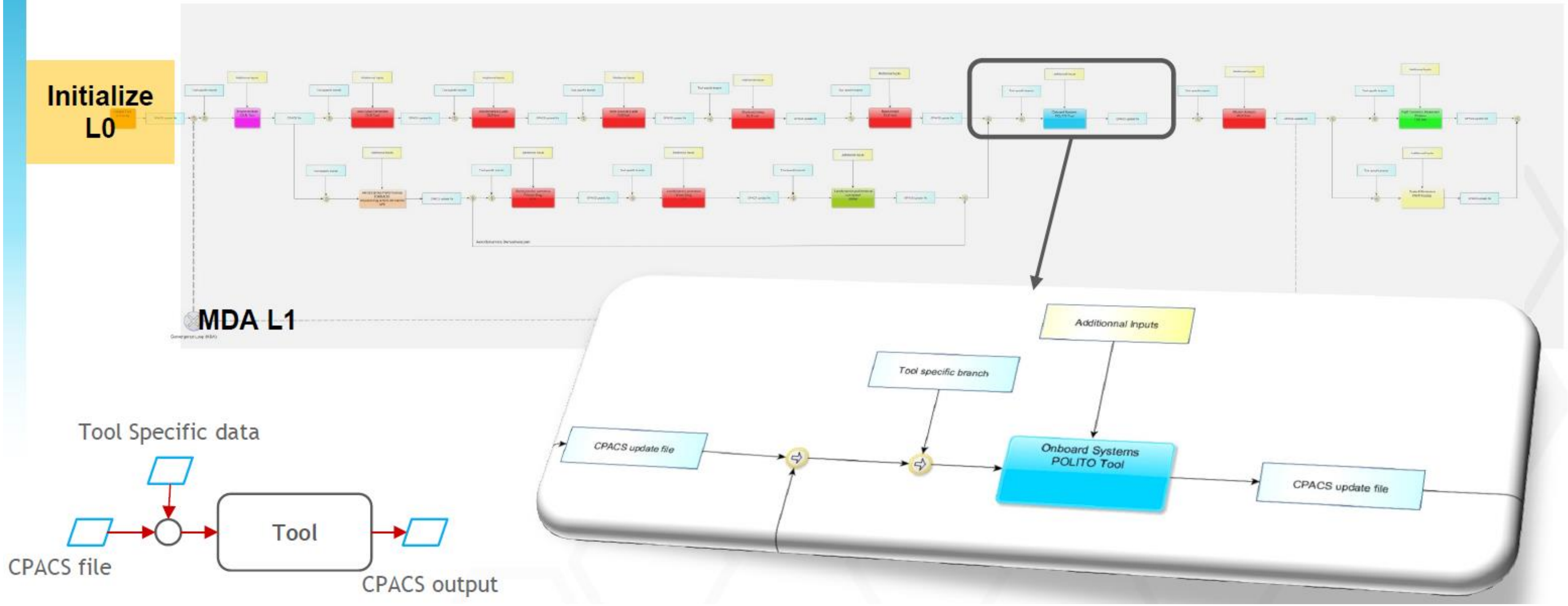
## Preliminary aircraft design




**Looking at these steps:**

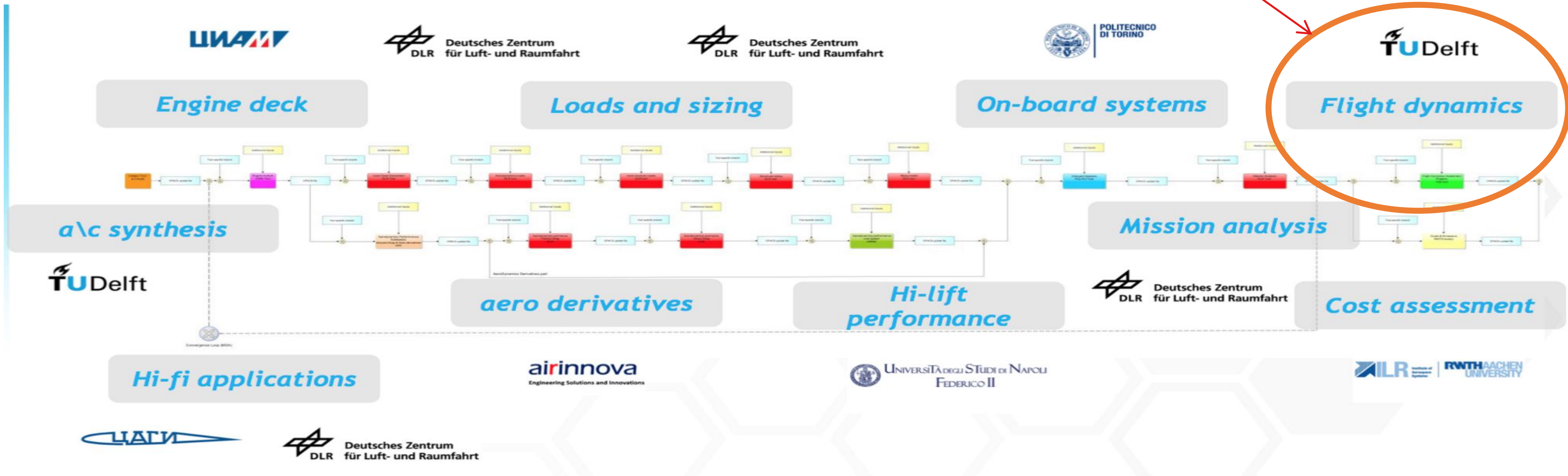
- **Absolute performance is not relevant**
- **Key is how our *tools impact these steps***
  - **Timescale impact**
  - **Improve fidelity**
  - **Reduce re-work**
  - **Requirements validated earlier**

# DC-1 MDA Final setup



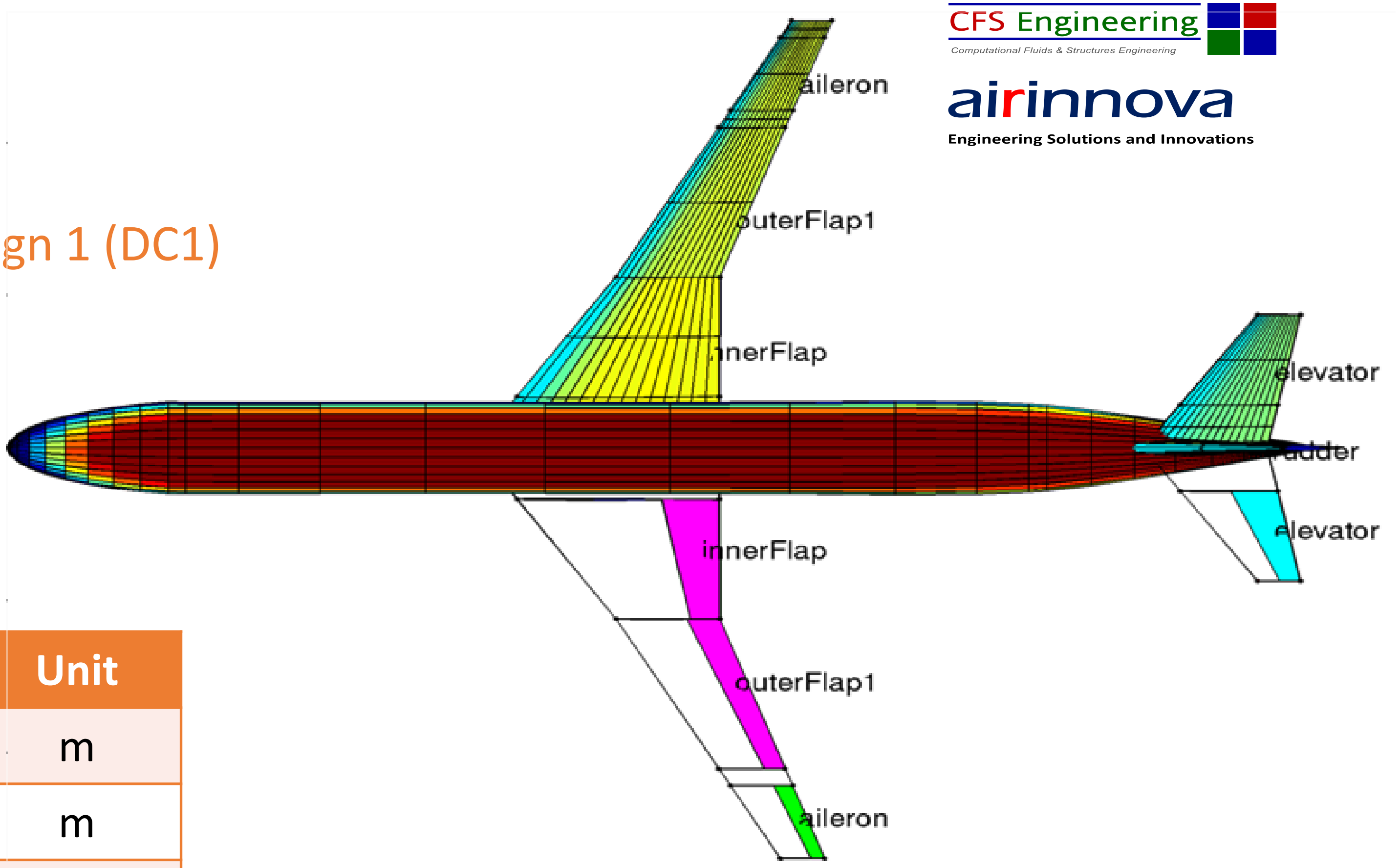
# Context: DC-1 MDA

We are here!



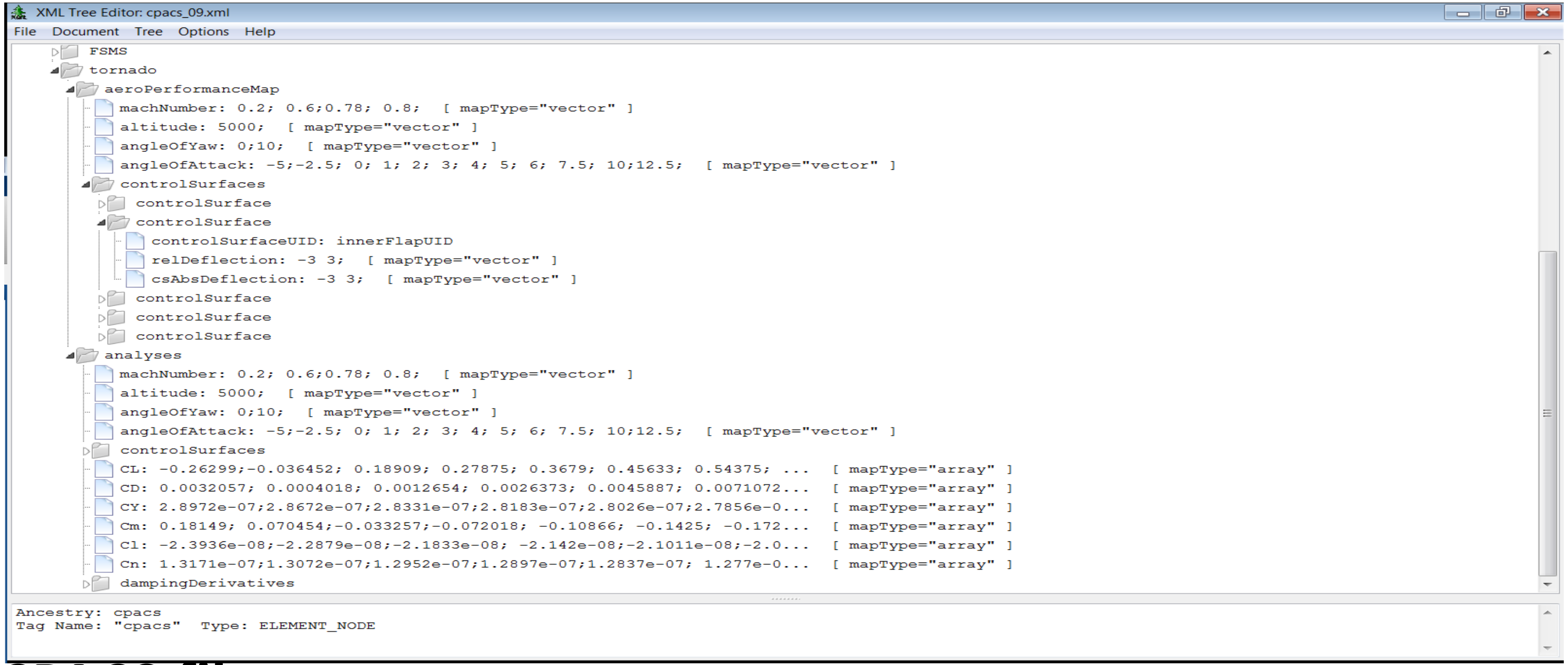
# 3. DC1-MDA Aircraft Example

- Aircraft used for the AGILE Design Campaign 1 (DC1)
- Result of Design Campaign 0 (DC0)
- From semi-empirical methods
- Medium-range commercial airliner
- No experimental data available




| Parameter | DC1-MDA | Unit |
|---|---|---|
| Wing span | 28.1 | m |
| MAC | 3.73 | m |
| Wing area | 82.8 | $m^2$ |
| MTOW | 39’750 | kg |

# Step 1 - CPACS file received

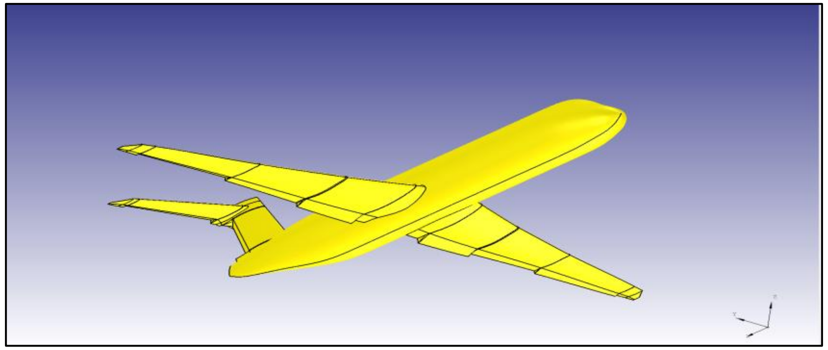


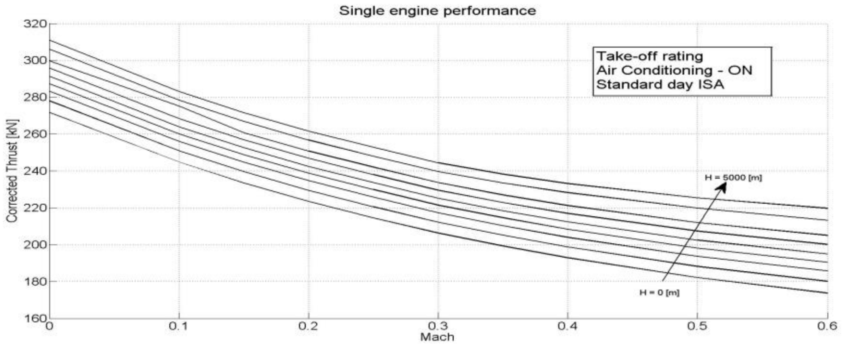

**Example - CPACS file**

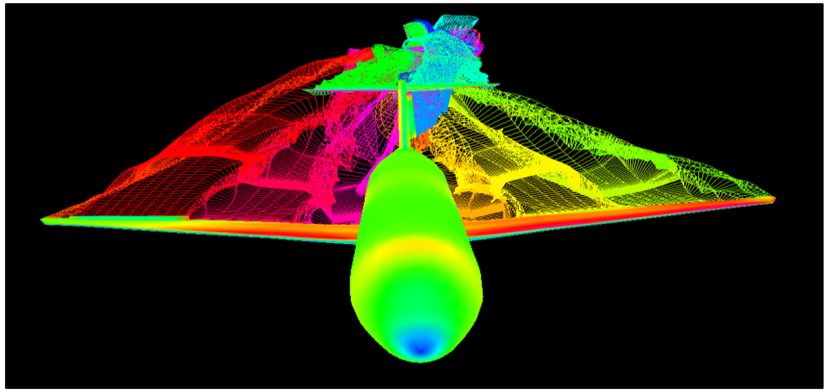
# Required data

CPACS file must contain:

- Aerodynamic dataset (stability and control derivatives)
- Propulsion system data
- Mass breakdown data (mass, cg, Inertia)
- Geometric data



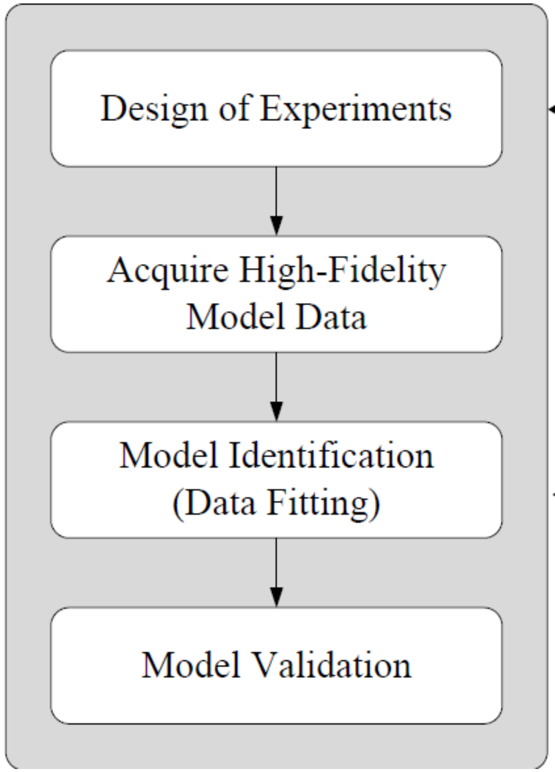


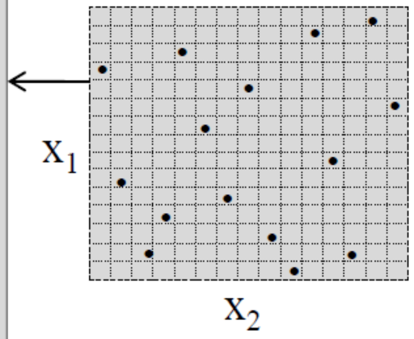



# 2. CEASIOM history and current status

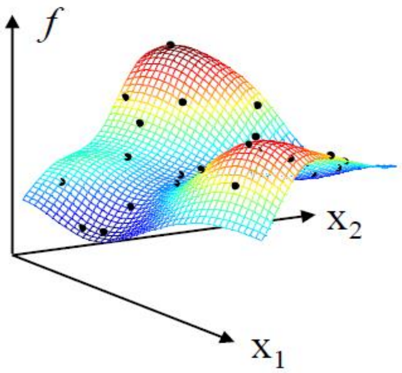
- Data fusion for aero-database for S&C
- Under development within AGILE
  - Making CPACS compatible

1. Initializasion
2. Sampling
3. Co-Kriging surrogate model
4. Sampling updates
5. Final surrogate model



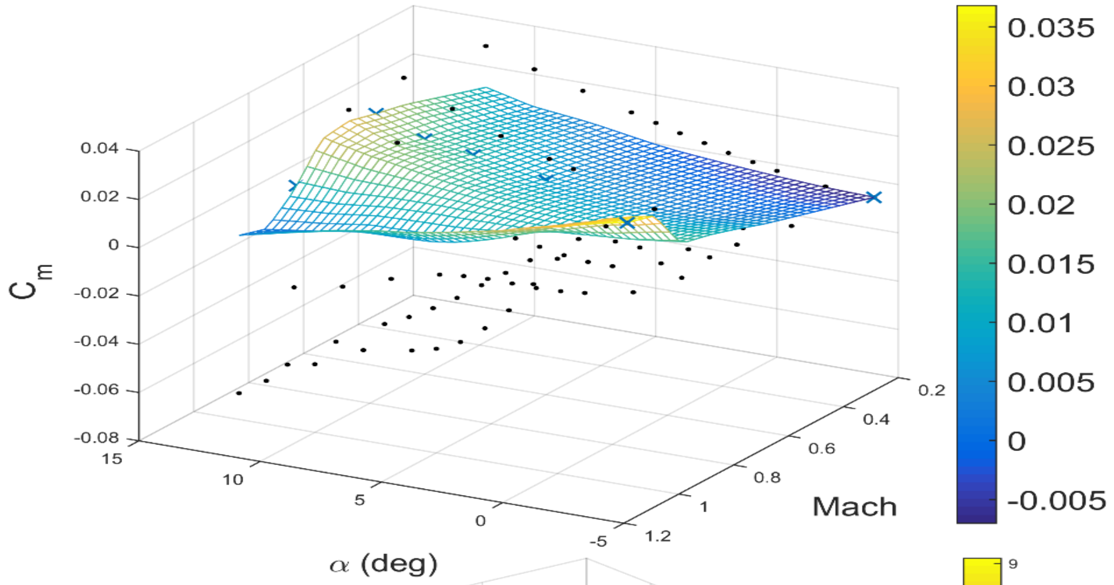



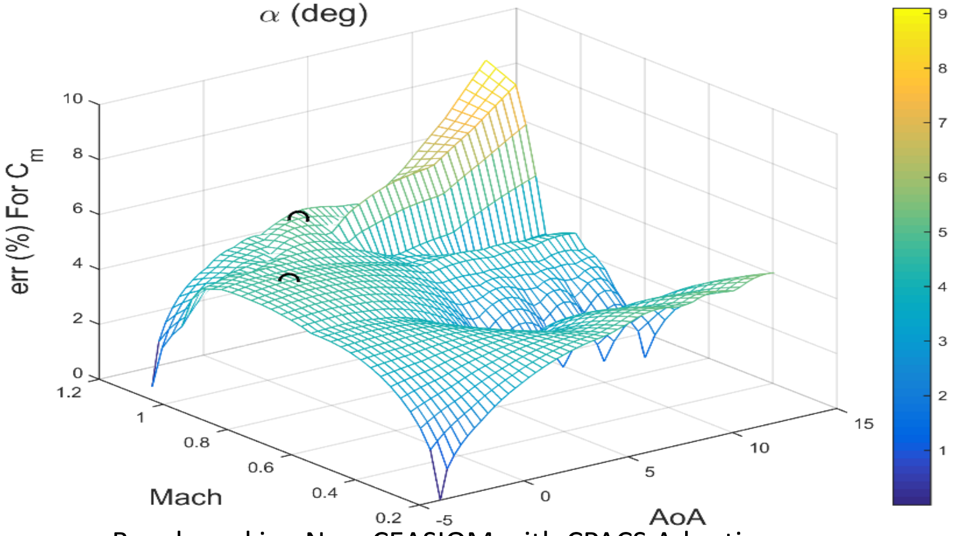

- Polynomial regression
- Radial basis functions
- Kriging
- Support vector regression
- Neural networks
- Gaussian processes



# 2. CEASIOM history and current status

- Smart sampling: Correct overall predictions by suggesting hi-fi samples at recommendation locations
- (in progress) scripting for automatically setting up and executing variable fidelity analysis
- 4D independent variables at most (CPACS format)



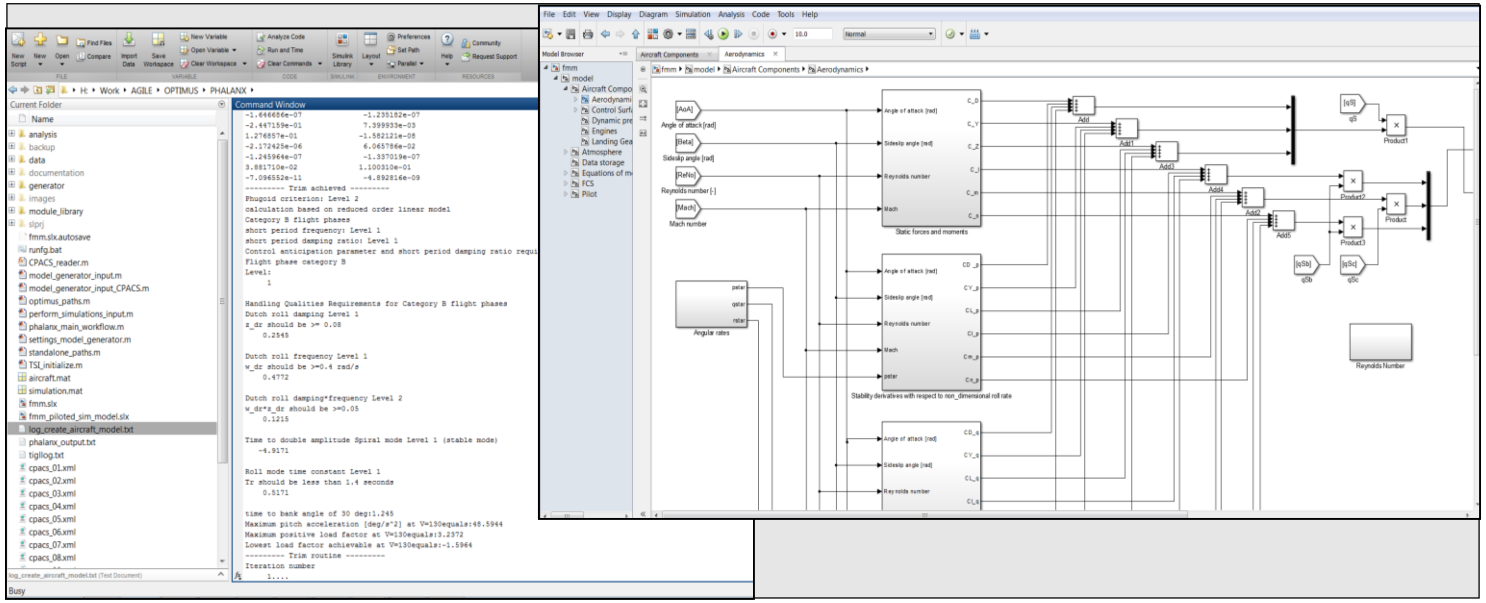




Benchmarking New CEASIOM with CPACS Adoption

# Step 2 – Create PHALANX simulation model

**P**erformance, **Ha**ndling Qualities, **L**oads **An**alysis Toolbo**x**

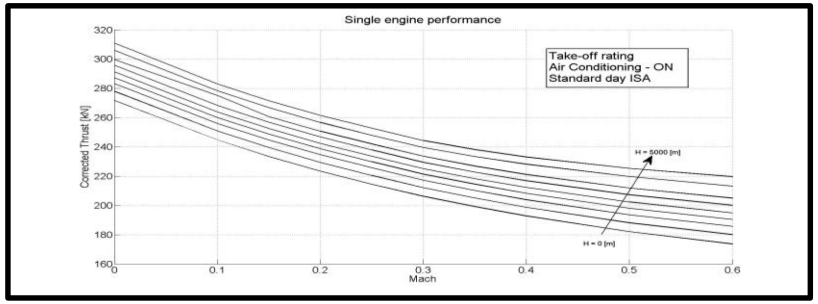
- Automatic generation of simulation model
- Equations of motion based on multibody dynamics (nonlinear flight dynamics model)
- Selective fidelity (range of sub models is available)



# Selective fidelity (example)

- CPACS file contains **detailed engine decks** (thrust, fuel flow as function of Mach, altitude and throttle setting)

Engine modelled using **look-up tables** in PHALANX




- Only **basic engine data available** (location on aircraft, bypass ratio and maximum thrust)

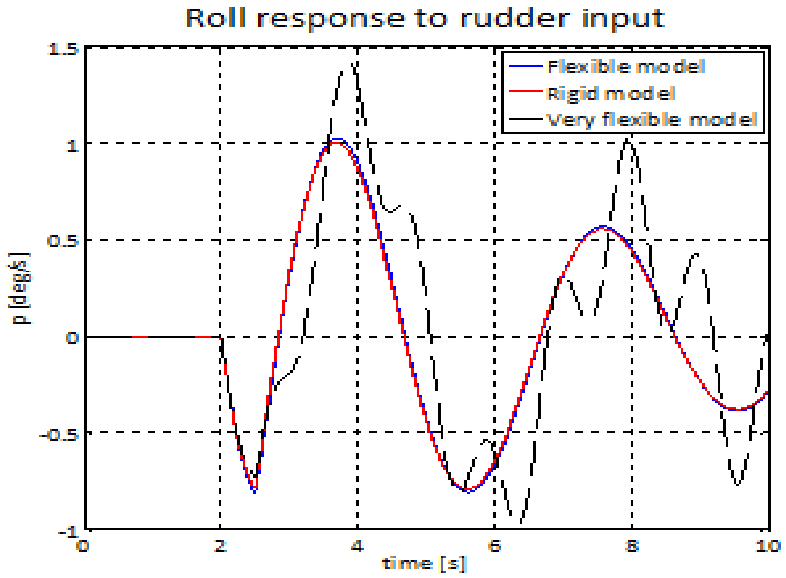
Engine modelled using **analytical functions** that accurately model thrust lapse as function of altitude and Mach number based on bypass ratio

$$\frac{T}{T_0} = A - \frac{0.377(1+BPR)}{\sqrt{(1+0.82BPR)G_0}} ZM + (0.23 + 0.19\sqrt{BPR})XM^2$$

# Step 3 – virtual flight test

- Trim and handling qualities analysis

  (for range of flight conditions)

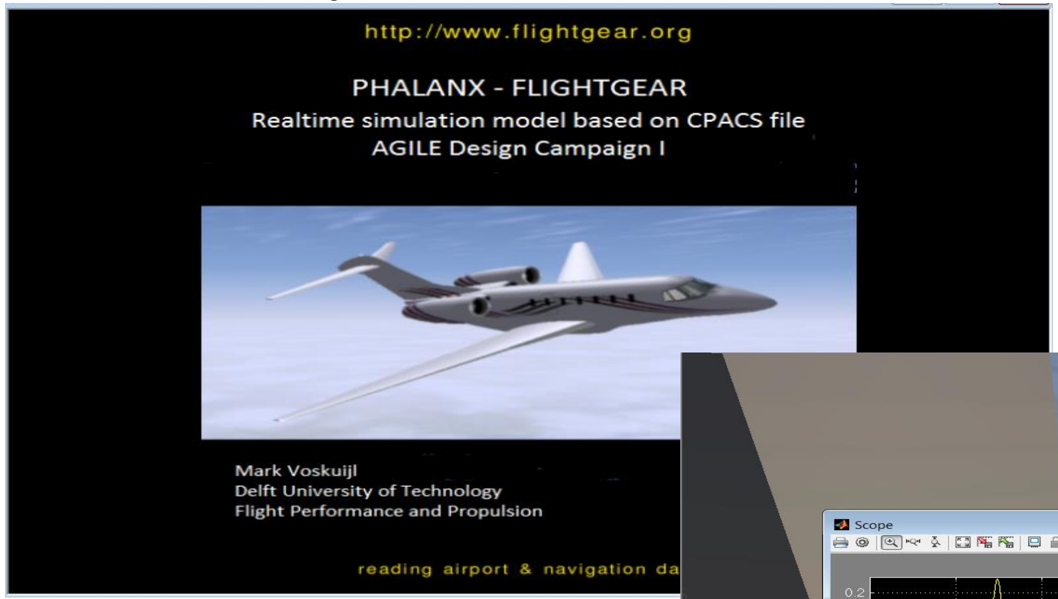



**Example time domain simulation**

**Basic results**

- Trim attitudes and control settings
- (including crosswind / engine out)
- Short period
- Phugoid
- Dutch roll
- Spiral
- Roll mode
- Push pull manoeuvre simulation
- Roll manoeuvre simulation
- Gibson criterion
- Maximum pitch acceleration (take-off)
- Response to turbulence and gusts

# Step 4 – Piloted simulation

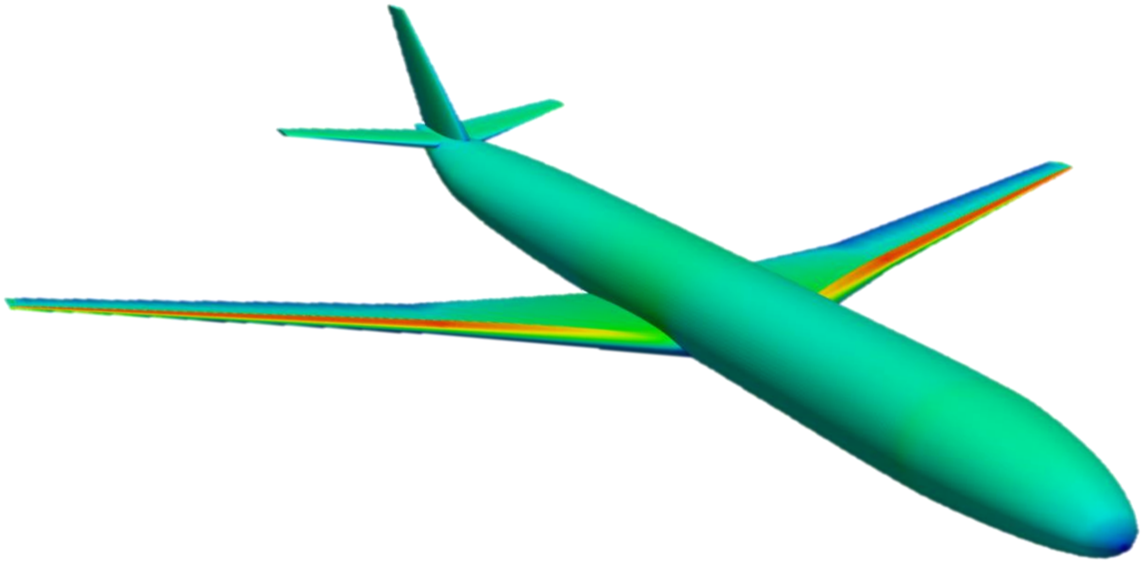



# Movies

- Pitch maneuvers:
  - Angle of attack
  - Pitch rate
  - Pilot input (roll)

- Roll maneuvers:
  - Roll rate
  - Pilot input (roll)
  - Pilot input (pitch)

- Rollover:
  - Roll rate
  - Load factor
  - Pilot input (roll)



- Questions ?

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# Challenge for Swedish Aerospace to remain competitive

## DLR supports Airbus with computational tools

- ✓ Example: writing new modern code ***FLUCS*** to replace ***Tau***: high order, large scale computing (exaflop)
- ✓ Integrated design, MDO aero-structures

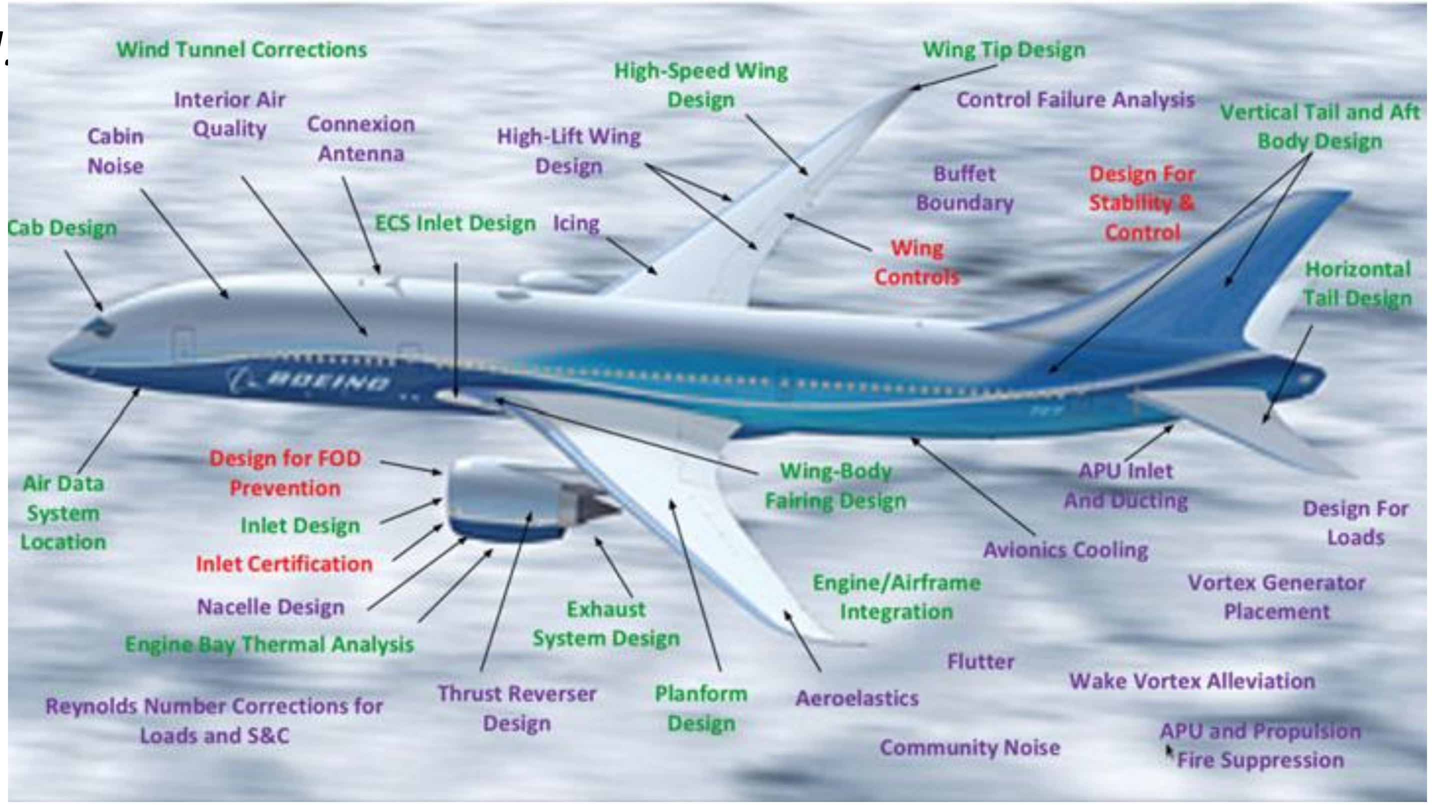
## CFD challenges in aerospace industry:

- ✓ Mihai's presentation, Spalart paper, *Aero J.*
- ✓ Algorithms and physical modeling
- ✓ Integrated with other disciplines for MDO
- ✓ Hybrid RANS-LES
- ✓ Improved user interfaces
- ✓ Example: **Off-design flow physics**

## HPC challenges

True exaflop performance

See Mihai's presentation … *significant*!



# Interests & Expectations – C3FD

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- ***New CFD code for aeronautical applications***
  - ✓ Developed from "scratch"
  - ✓ Based on knowledge from Edge and other codes
  - ✓ Finite volume (DG like)
  - ✓ Allow for Higher Order
  - ✓ HPC, highly scalable, high efficiency
- Open source under appropriate license
  - ✓ OpenFoam type
  - ✓ Allow for proprietary developments / additions
- ***Design & Optimization***
  - ✓ Linearized equations, Jacobians for adjoint and/or implicit treatment
  - ✓ ***Surrogate-based optimization***
- Allow coupling & solving with structures – multi-physics
  - ✓ Integrated aero-structures design

Airinnova C3FD Proposal – design optimization
*Variable fidelity Surrogate-based optimization*

# C3FD, some thoughts

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- ❑ New CFD code for aeronautical applications
  - ✓ New code developed from “scratch”
  - ✓ Based on knowledge from Edge and other codes
  - ✓ Minimum inclusion of existing parts of codes
- ❑ Focus on unstructured grids for realistic large scale applications
  - ✓ Finite volume, Finite Element (DG like)
  - ✓ Finite difference in structured domains/blocks
  - ✓ Allow for Higher Order (FE, FD)
  - ✓ HPC, highly scalable, high efficiency
- ❑ Open source under appropriate license
  - ✓ OpenFoam type
  - ✓ Allow for own proprietary developments
- ❑ Multiphysics
  - ✓ Navier-Stokes
  - ✓ Allow for solving and coupling with structures, heat transfer …
- ❑ Design & optimization
  - ✓ Linearized equations, Jacobians for adjoint and/or implicit treatment
  - ✓ …

# C3FD, continued

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- Work plan
  - ✓ Prototype code produced within a year
  - ✓ Contents of prototype to be discussed, e.g. FV + DG + Fluid + Structure
  - ✓ To be reviewed & approved and further extended
- Related similar projects
  - ✓ Flux at DLR (FV, DG, adjoints …)
  - ✓ SU2 in US
  - ✓ OpenFoam
- Programming details
  - ✓ Minimize code volume (# lines)
  - ✓ Python, Fortran, C++ … ???
  - ✓ Classes, …